AD-A066 718 CATHOLIC UNIV OF AMERICA WASHINGTON D C HUMAN PERFOR--ETC F/G 5/10
IDENTIFICATION OF PSYCHOLOGICAL FEATURES IN THE RECOGNITION OF --ETC(U)
DEC 78 J H HOWARD N00014-75-C-0308
UNCLASSIFIED TR-78-10-ONR NL

| OF |
AD
A066718

END
DATE
FILMED
5-79
DDC

LEVEL II

(12)

FINAL REPORT

IDENTIFICATION OF PSYCHOLOGICAL FEATURES IN THE RECOGNITION OF COMPLEX, NONSPEECH SOUNDS

James H. Howard, Jr.

ONR CONTRACT NUMBER N00014-75-C-0308

Technical Report ONR-78-10

Human Performance Laboratory
Department of Psychology
The Catholic University of America

December, 1978

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER ONR-78-10	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) IDENTIFICATION OF PSYCHOLOGICAL FEATURES IN THE RECOGNITION OF COMPLEX, NONSPEECH SOUNDS		5. TYPE OF REPORT & PERIOD COVERED FINAL REPORT 1 Oct 1974 - 31 Dec 1978
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) James H. Howard, Jr.		8. CONTRACT OR GRANT NUMBER(s) N00014-75-C-0308
9. PERFORMING ORGANIZATION NAME AND ADDRESS The Catholic University of America Washington, D. C. 20064		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS NR 197-027
11. CONTROLLING OFFICE NAME AND ADDRESS Engineering Psychology Programs, Code 455 Office of Naval Research		12. REPORT DATE December 1978
		13. NUMBER OF PAGES 17
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) TR-78-10-ONR		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

auditory perception
auditory pattern recognition
auditory features
auditory classification
feature extraction
feature selection
multidimensional scaling
decision processes

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report summarizes the research conducted ~~under contract N00014-75-C-0308~~ between the Office of Naval Research, Engineering Psychology Programs and The Catholic University of America. The research investigated the perceptual processes involved in the recognition of complex nonspeech sounds, particularly those that resemble steady-state passive sonar signals. The individual experiments conducted in this pursuit have been distributed in nine technical reports and ten additional papers. The issues addressed in this work concerned three general problem areas: (1) iden-

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

S/N 0102-014-6601

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

409 381 79 03 30 186

Block 20 continued

tification of perceptual features, (2) aural feature selection processes, and (3) aural classification processes. The methods, substantive contritution and practical implications of the research are outlined.

ACCESSION for
NTIS Section
DDC Buff Section
BY
DISTRIBUTION/AVAILABILITY CODES
SPECIAL
A

This report summarizes the research conducted under contract N00014-75-C-0308 between the Office of Naval Research, Engineering Psychology Programs and the Catholic University of America. The research investigated the perceptual processes involved in the recognition of complex nonspeech sounds, particularly those that resemble steady-state passive sonar signatures. The individual experiments conducted in this pursuit have been distributed in nine technical reports and ten additional papers (see Appendix A for a complete listing). The issues addressed in this work may be classified into three general areas: (1) identifying perceptual features, (2) aural feature selection processes, and (3) aural classification processes. The substantive contribution of each report is described below following this overall organization.

(1) Identifying Perceptual Features

Problem and rationale. Recent years have witnessed major theoretical advances in our understanding of the perceptual processes involved in the detection and discrimination of simple acoustic stimuli. In contrast, relatively little is known about the psychological processes that underlie the classification of complex acoustic signals. A popular approach to the analysis of this problem assumes that human auditory recognition involves several distinct information-processing stages. In this view an unknown sound undergoes several transformations before it is recognized. First, an initial sensory representation of the signal is formed. Second, this preliminary representation is further transformed into a set of distinctive auditory features. This stage is referred to as feature extraction and is generally thought to involve the reduction of a stimulus to its essential characteristics. Third, this highly processed feature representation is compared with information stored in memory to determine its classification. The processes involved in this stage may be extremely complex

and are collectively referred to as the decision stage.

Although no single theoretical statement of the feature extraction process exists, recent research has stressed its importance in auditory perception. It is frequently argued that the feature extraction process is "tuned" to select perceptually important information from the output of the preliminary analysis stage, and discard information that is likely to be unimportant. Since aural recognition performance ultimately depends on the feature extraction process, a central objective of our research was to investigate techniques that would enable us to identify those acoustic cues that are of primary psychological importance.

The object of this investigation, the feature representation or output of the feature extraction stage, is obviously not directly observable and must therefore be inferred using indirect methods. Although a variety of techniques have been used in previous research, we selected multidimensional scaling for further investigation. With this method, listeners are asked to provide pairwise similarity judgments on the set of sounds of interest. A specific multidimensional scaling algorithm is then applied to decompose the resulting subjective proximity matrix into an n-dimensional metric space in which each signal is represented as a single point or vector. If a satisfactory scaling solution exists, we assume that the dimensions of the scaled stimulus space reflect those features that the listeners used to compare the stimuli. A comparison of the perceptual space and the known physical structure of the stimuli can reveal the specific psychophysical transformations involved in the feature extraction process.

Three experiments were conducted specifically to investigate these techniques. In the first, we confirmed the validity of the method by scaling a set of engine-like sounds that had previously been investigated using other methods. In the second study we extended these techniques to a new set of eight passive sonar signals. In the third study additional evidence relevant to the

feature identification problem was obtained for brief-duration signals in a backward-masking task. The results of the first two studies clearly established the effectiveness of multidimensional scaling techniques for identifying the perceptual features used by listeners in a similarity rating task. In addition, the techniques we used enabled us to specify the relative importance of stimulus features and to characterize the differences between specific groups of listeners in a precise way. The third study revealed some interesting task-dependencies. These findings have been followed up in subsequent research. The three reports are abstracted below.

Report ONR-75-1. The INDSCAL multidimensional scaling model was used to investigate the distinctive features involved in the perception of sixteen complex nonspeech sounds. The signals differed along four physical dimensions: fundamental frequency, waveform, formant frequency and number of formants. Scaling results indicated that an individual's similarity ratings could be accounted for by three psychological or perceptual dimensions. A statistically reliable correspondence was observed between these perceptual dimensions and the physical characteristics fundamental frequency, waveform, and a combination of the two formant paramenters. These results were further explored with Johnson's (1967) hierarchical clustering analysis. Large differences in featural saliency occurred in the group data with fundamental frequency accounting for more variability than the remaining dimensions. Further analysis of individual listener data revealed large individual differences in featural saliency. These differences were related to past musical experience of the listener and to earlier findings using similar signals. It was concluded that (1) the INDSCAL model provides a useful model for the analysis of auditory perception in the nonspeech mode, (2) featural saliency in such sounds is likely to be determined by an unspecified attentional mechanism.

The implications of these findings for tactical sonar operations were discussed.

Report ONR-76-2. The potential usefulness of multidimensional scaling techniques in the perceptual analysis of "real world" underwater sounds was demonstrated. Nineteen observers (nine with musical training, ten without) used a five-point scale to judge the similarity of all possible pairs of eight passive sonar recordings. The eight signals were selected to represent a range of common natural and man-made underwater sounds. These data were analyzed using the INDSCAL multidimensional scaling model, revealing an interpretable two-dimensional psychological space. One of the psychological dimensions was interpreted as reflecting the overall shape of the 1/3-octave spectra of the eight signals, while the second was seen to reflect the prominence of a low-frequency periodicity present in some signals. Individual observer analysis revealed substantial differences between the musically trained and musically inexperienced observers in the relative importance or salience of the two dimensions. The relation of these findings to earlier work was discussed.

Report ONR-77-3. Three experiments investigated the effect of an interfering white noise on the recognition of brief-duration complex sounds. Listeners were presented with a 20-msec signal followed, after a variable delay, by a 500-msec white noise burst. Their task was to classify the signal into one of two categories on the basis of either its fundamental frequency, waveform or formant frequency. The main focus of the experiments was to investigate the relation between performance and the auditory features or cues present in the signal. Recognition performance improved with increasing inter-stimulus intervals up to an asymptote at approximately 200 msec. This finding is consistent with earlier results in suggesting that brief-duration signals are retained for a short time in a precategorical sensory memory for further processing. In addition, the data revealed that asymptotic performance level was determined primarily by the distinctiveness

or discriminability of the relevant auditory feature and by the amount of listener experience with the relevant feature. It was concluded that practiced listeners have an improved ability to selectively focus their attention on specific auditory cues in a complex aural display.

(2) Aural Feature Selection Processes

Problem and rationale. In the research outlined above we focused on the problem of identifying the features that listeners actually use to compare complex sounds. Once the reliability of multidimensional scaling techniques had been established in this context, more fundamental questions could be addressed. In particular, the feature extraction process had not been well-specified in the literature. No true psychological theory of feature extraction existed. When we say that a stimulus is reduced to its "essential elements," what do we mean? How do listeners determine these crucial elementary units of perception? Implicit in our approach to this problem was the understanding that a feature tuning process exists whereby the set of distinctive features was defined. We referred to this as the feature selection problem. The specification of a general feature selection theory will enable us to predict the features that listeners will use in perceiving complex sounds.

Two contrasting approaches to this problem have been suggested in the literature. First, the human auditory system may be equipped with a set of specific feature-detecting mechanisms that monitor incoming aural information for particular stimulus cues. Here it is assumed that the tuning process has occurred through natural selection, and that evolutionary mechanisms have provided us with the neural apparatus needed to detect these features. This approach emphasizes the importance of the feature detectors themselves. Each detector "looks for" an individual stimulus property, and a set of feature detectors determines a property list for the stimulus. Second, it is possible that the

auditory system has an internalized set of rules and criteria for feature selection rather than a set of narrowly tuned feature detectors. These rules and processes enable the listener to determine what the comparison features should be in any particular stimulus context.

Our research has favored the latter view. While we are not prepared to deny the existence of specialized neural detectors for some attributes (e.g., for speech cues), the more flexible, process-oriented approach has seemed more appropriate for timbre perception on both logical and empirical grounds. In the first report on this research we carefully articulate the two contrasting positions outlined above and consider earlier findings (both from our laboratory and from others) in terms of this issue. In the second report, we propose a specific structure-preserving feature-selection model and demonstrate its ability to predict the features that listeners use to compare complex steady-state sounds. We see the proposed theory as a first step toward the specification of a general feature-selection model. The two reports are abstracted below.

Report ONR-78-5. Feature extraction plays a fundamental role in most theories of pattern recognition, but despite its importance, the extraction process is not well defined. Two contrasting views of feature extraction were identified in this review paper, one which emphasizes invarient feature detection and one which emphasizes flexible feature selection. The invariant detector approach assumes that the auditory system is equipped with finely tuned feature detectors that respond to specific stimulus properties. In this view, stimuli are described in terms of property lists of specific features. In contrast, the more flexible, process-oriented approach assumes that the auditory system is equipped with a set of rules and criteria for feature selection. In this view, the important perceptual features reflect the underlying structure of the stimuli. Research on timbre and pitch perception has supported a flexible, process-oriented approach. The flexibility of this approach offers particular advantages in that it can explain

the effects of stimulus and task context on performance. Both types of context influence the perception of complex sounds. Stimulus context affects the structure of the stimulus space and consequently the features that would be extracted by a structure-preserving transformation. Task context affects the relative importance of features in making similarity judgments and classification decisions. The two approaches to feature extraction have important implications for the development of auditory pattern recognition theory.

Report ONR-78-6. A process-oriented feature selection model was proposed to characterize listeners' comparisons of the timbre of complex steady-state sounds. Specifically, the model assumes that the listener performs a structural analysis on the low-resolution spectra of the stimuli to be compared and then extracts a feature representation through a structure-preserving transformation resembling a principal-components analysis. This feature representation is subsequently employed to make similarity judgments between stimuli. Predictions of the model for a timbre-comparison task were examined using a set of sixteen complex sounds that varied in amplitude spectral shape. The subjective feature representation obtained from the ALSCAL nonmetric scaling program was generally consistent with the theoretical feature representation produced by the optimal structure-preserving transformation applied to the loudness-weighted spectra. The two comparison features as well as the relative importance of the two dimensions were successfully predicted by the model. Practical implications for the subjective evaluation of complex signals are discussed and refinements to the transformations in the model are suggested.

(3) Aural Classification Processes

Problem and rationale. In order to develop a complete understanding of the aural classification process, it is necessary to clarify the relation between the feature extraction and decision stages. How are the characteristic features

that listeners extract used to determine signal classification? The overall question addressed in the third phase of our research concerned the relation between the perceptual features identified in a multidimensional scaling analysis and the decision stage of the aural classification process. In a classification task, the listener is required to distinguish among a specified set of acoustic patterns. Consequently, one would expect the decision process to selectively emphasize one or another distinctive feature, depending on the configuration of stimuli in the perceptual pattern space. For example, given a set of stimuli which differ in both pitch and loudness, listeners would likely use both features to evaluate pairwise similarity. On the other hand, if the same signals were then grouped into two categories based on only a single dimension (e.g., high and low pitch), then listeners learning this partition need only consider a single feature, pitch, to achieve optimal classification performance.

In our first study in this series we proposed and tested a specific, bottom-up model of the aural classification process. The model is bottom-up in that classification is based on a systematic and extensive analysis of low-order feature information. In the model we assumed that a decision processor estimates the perceptual distance between the to-be-classified stimulus and each of a set of category prototypes in the feature space. This is used to estimate the likelihood of each category given that stimulus. The stimulus is then classified into the category having the greatest likelihood. This model differs from earlier efforts in at least two respects: (1) it is oriented toward multidimensional rather than unidimensional stimuli, and (2) we propose that a feature-tuning process occurs whereby the relative importance of stimulus features are adjusted to optimize classification performance. The four experiments outlined in the first of these reports investigated classification using a set of synthetic cavitation signals. Overall, the data were supportive of the model.

Our second study addressed an issue raised in the research discussed above. Specifically, we examined the long-term stability of our theoretical predictions. Can the model adequately predict the confusions that listeners will make after extended practice? Perhaps listener sensitivity changes or new features emerge for highly practiced listeners? The results of this study were generally consistent with the model. Although some listeners seemed to "discover" perceptually difficult features only after considerable practice, very little change occurred over the final twelve sessions in the experiment.

Another issue of some interest concerns the ability of our aural classification model to characterize individual listener performance. Large individual differences were frequently noted in our classification research. In this study we were interested in predicting an individual's confusion data in one classification task after observing his or her performance in another. The results revealed that an overall attentional effort parameter was similar for the same individual across very different classification tasks. This suggests that our aural classification model may be useful in characterizing individuals as "good classifiers" or " poor classifiers" as well as in predicting the specific confusions that will occur in a number of different classification tasks.

The final study undertaken in this series addressed a broader issue. Our previous experiments on the classification of complex sounds used categories defined by two exemplars. One objective of the present study was to test the generality of the model by examining classification performance in a four-exemplar categorization task. A second objective of this study was to obtain additional evidence regarding the classification rules that listeners use. Our classification model is based on the assumption that listeners compare a sound with each of a

series of prototypes to determine its correct classification. Although this assumption has been supported in several experiments, other possible decision rules have not been considered explicitly. Two possible models of how category information is represented subjectively were examined in this study: the prototype-distance and attribute-frequency models. The prototype model argues that in a classification task a prototype or best example of a category is formed by averaging the distinctive features of the category members. In contrast, the attribute-frequency model assumes that the best example of a category is simply that item whose features or attributes occurred most frequently in the category exemplars. Our findings indicated that the classification model will adequately handle the four-examplar situation, but also indicated that the prototype assumption may not be the most appropriate in all conditions. Each of the four studies in this series are abstracted below.

Report ONR-78-4. The relation between the perceptual features identified in a multidimensional scaling (MDS) analysis and the decision stage of the auditory classification process was investigated in four experiments based upon a set of sixteen complex acoustic patterns. The sounds consisted of broad-band white noise, amplitude modulated by sawtooth waves of varying frequency and attack. A psychological feature representation of the stimuli was obtained in Experiment 1 using a MDS analysis (INDSCAL) of the listeners' pairwise similarity ratings. Two groups of listeners in Experiment 2 learned to classify each of the sixteen signals into one of eight categories (two sounds per category). The two groups learned eight-category partitions that emphasized different features of the stimuli. Confusion matrices were analyzed in terms of both the stimulus space obtained in Experiment 1 and a probabilistic model of the listener's decision process. The model provided a reasonable fit to the observed data. Experiments 3 and 4 further tested the assumptions of the

decision model. In Experiment 3, listeners were required to classify each member of a large set of amplitude-modulated signals that formed a "grid" over the perceptual feature space. Subjective probability density functions for the eight categories estimated from listener responses using potential function or Parzen estimator techniques were consistent with those assumed by the model. In Experiment 4, MDS techniques were used to investigate the "conceptual space" underlying the listeners' memory for each of the eight categories in both groups. Category coordinates obtained from the MDS analysis corresponded well to the category centroids computed from the perceptual space of Experiment 1. Overall, results of the four experiments indicated that listeners employed an optimum-processor strategy to determine the relative importance of each feature in the decision process. The findings indicate that any theoretical treatment of auditory pattern recognition must address the interaction of the feature extraction and decision processes.

Report ONR-78-7. Four listeners were given extended practice in an eight-category classification task (3072 trials). The stimuli were sixteen amplitude-modulated noise patterns that varied in modulation frequency (Tempo) and attack (Quality). Two listeners learned an eight-category partition that was based primarily on stimulus Quality, and two learned a partition that was based primarily on stimulus Tempo. The resulting confusion data were analyzed in terms of our aural classification model. The theoretical analysis enabled us to specify the relative emphasis placed on the two stimulus features by each listener on each of the sixteen trial blocks. The results indicated that although large individual differences occurred, all listeners had more difficulty making use of the subtle stimulus differences along the Quality dimension than they did of differences along the Tempo dimension. Three of the four listeners placed a greater emphasis on Tempo than would be optimal. Although one listener only "discovered" the Quality dimension after 750 trials, very few changes occurred for any listener

after 1000 trials. It was concluded that extensive practice alone is not likely to improve a listener's ability to use difficult features in aural classification. The role of sensory factors in limiting performance was considered.

Report ONR-78-8. Our proposed classification model estimates attentional capacity and how it is allocated to the relevant dimensions. It was hypothesized that capacity will vary as a function of individuals, but that the allocation of capacity is a function of dimensional relevance. A classification experiment was conducted using amplitude-modulated noise with modulation frequency (Tempo) and waveform attack (Quality) as relevant dimensions. Listeners were required to classify sixteen sounds into eight categories emphasizing one of the dimensions for eight blocks (1536 trials) and then the other dimension for eight blocks. Capacity was estimated by the model and was equivalent for both classification tasks for individuals. Allocation of capacity reflected dimensional relevance.

Report ONR-78-9. Our prposed classification model assumes that each category in a classification task is represented by an abstract prototype. Others have argued that the evidence for prototype representations can be explained by the indeterminancy of exemplar attributes. A test of these two models would require that attribute indeterminancy be measured. In a classification task, attribute indeterminancy can lead to overlapping category boundaries. In turn, this results in confusions, which can then be a measure of indeterminancy. An aural classification experiment was conducted where listeners classified sixteen amplitude-modulated noise patterns into one of four categories, each having four examplars. Results of a post-training recognition test indicated that an unexperienced prototype was rated as familiar, but this effect was

reduced with increased practice with the category exemplars. Neither model was supported unequivocally. Classification results did demonstrate that the classification model is applicable to four examplar categories defined in two dimensions.

(4) Summary

A number of general conclusions are justified on the basis of our findings. (1) Multidimensional scaling provides a set of useful techniques for identifying the perceptual features that listeners use to evaluate complex sonar-like sounds. These methods also permit a precise quantitative specification of individual and group differences as well as an assessment of the relative importance of specific features. (2) Caution must be exercised, however, in generalizing the aural features identified in one situation to other task contexts. Our research has demonstrated that considerable, task-related variability can occur in the relative subjective importance of individual features. The most important feature in one task is not necessarily the most important in another, even though both tasks may involve the same stimuli. (3) Our feature selection model provides a reasonable preliminary specification of how listeners determine which features to use when comparing complex, steady-state sounds. (4) The aural classification model proposed in the present research can successfully predict the specific confusion errors that listeners make in a wide range of classification tasks. When coupled with the feature-selection model, the classification model provides a potentially very powerful method for anticipating the "fine structure" of aural classification data. The contribution of such knowledge to the development of acoustic preprocessing devices or other performance aids is obvious.

Appendix A: Bibliography

Technical Reports

Howard, J. H., Jr. & Silverman, E. B. Structural components in the perception of sixteen complex sounds (Technical Report ONR-75-1). Washington, D.C.: The Catholic University of America, Human Performance Laboratory, August, 1975.

Howard, J. H., Jr. The psychophysical structure of complex underwater sounds (Technical Report ONR-76-2). Washington, D.C.: The Catholic University of America, Human Performance Laboratory, September, 1976.

Silverman, E. B. & Howard, J. H., Jr. Recognition of three distinctive features in brief-duration complex nonspeech sounds (Technical Report ONR-77-3). Washington, D.C.: The Catholic University of America, Human Performance Laboratory, September, 1977.

Howard, J. H., Jr., Ballas, J. A., Burgy, D. C. Feature extraction and decision processes in the classification of amplitude-modulated noise patterns (Technical Report ONR-78-4). Washington, D.C.: The Catholic University of America, Human Performance Laboratory, July, 1978.

Howard, J. H., Jr. & Burgy, D. C. Structure-preserving transformations in the comparison of complex steady-state sounds (Technical Report ONR-78-6). Washington, D.C.: The Catholic University of America, Human Performance Laboratory, December, 1978.

Howard, J. H., Jr. & Ballas, J. A. Classification of amplitude-modulated noise patterns with extended practice (Technical Report ONR-78-7). Washington, D.C.: The Catholic University of America, Human Performance Laboratory, December, 1978.

Ballas, J. A. & Howard, J. H., Jr. Predicting individual listener confusions in the classification of complex, steady-state sounds (Technical Report ONR-78-8). Washington, D.C.: The Catholic University of America, Human Performance Laboratory, December, 1978.

Ballas, J. A. & Howard, J. H., Jr. Two approaches to category representation in aural classification (Technical Report ONR-78-9). Washington, D.C.: The Catholic University of America, Human Performance Laboratory, December, 1978.

Other Papers

Burgy, D. C. Hemispheric asymmetries in the perception of nonspeech sound characteristics. Unpublished Masters Thesis, Department of Psychology, The Catholic University of America, 1978.

Howard, J. H., Jr. Psychophysical structure of eight complex underwater sounds. Journal of the Acoustical Society of America, 1977, 62, 149-156.

Howard, J. H., Jr. More on the statistical treatment of individual differences in multidimensional scaling. Perception & Psychophysics, 1977, 22, 106-107.

Howard, J. H., Jr. A multi-purpose laboratory package for OS/8 BASIC. Under editorial review.

Howard, J. H., Jr. & Ballas, J. A. Feature selection in auditory perception. In D. J. Getty & J. H. Howard, Jr. (Eds.), Auditory and visual pattern recognition. Hillsdale, N.J.: Erlbaum. In preparation.

Howard, J. H., Jr. & Silverman, E. B. A multidimensional scaling analysis of sixteen complex sounds. Perception & Psychophysics, 1976, 19, 193-200.

Howard, J. H., Jr., Burgy, D. C., & Ballas, J. A. A deglitching circuit for the AA50 D/A converter. Behavior Research Methods and Instrumentation , 1978, 10, 858-860.

Silverman, E. B. The recognition of the critical features of nonspeech sounds in a backward masking task. Unpublished Doctoral Dissertation, Department of Psychology, The Catholic University of America, 1975.

Silverman, E. B. & Howard, J. H., Jr. A general-purpose relay and amplifier I/O interface for the PDP-8/e computer. Behavior Research Methods and Instrumentation, 1976, 8, 498-500.

Wolskee, P. J. Effect of memory load on echoic memory. Unpublished Masters Thesis, Department of Psychology, The Catholic University of America, 1978.

Appendix B: Personnel

Principal Investigator

James H. Howard, Jr.

Graduate Research Assistants

James A. Ballas
Donald C. Burgy
Peter Doyle
Joseph I. Peters
Eugene B. Silverman
Patricia J. Wolskee

Undergraduate Research Assistants

Ann Destefano
James A. Galgano
Paul A. Mondor
Mary F. Santonestasso
James Stegmaier

DIRECTOR, ENGINEERING PSYCHOLOGY
 PROGRAMS, CODE 455
OFFICE OF NAVAL RESEARCH
800 NORTH QUINCY STREET
ARLINGTON, VA 22217

DEFENSE DOCUMENTATION CENTER
CAMERON STATION
ALEXANDRIA, VA 22314

CDR P. A. CHATELIER
OUSDRE (E&LS)
PENTAGON, ROOM 3D129
WASHINGTON, D.C. 20301

DIRECTOR, VEHICLE TECHNOLOGY
 PROGRAMS, CODE 211
OFFICE OF NAVAL RESEARCH
800 NORTH QUINCY STREET
ARLINGTON, VA 22217

DIRECTOR, WEAPONS TECHNOLOGY
 PROGRAMS, CODE 212
OFFICE OF NAVAL RESEARCH
800 NORTH QUINCY STREET
ARLINGTON, VA 22217

DIRECTOR, ELECTROMAGNETICS
 TECHNOLOGY PROGRAMS, CODE 221
OFFICE OF NAVAL RESEARCH
800 NORTH QUINCY STREET
ARLINGTON, VA 22217

DIRECTOR, INFORMATION SYSTEMS
 PROGRAM, CODE 437
OFFICE OF NAVAL RESEARCH
800 NORTH QUINCY STREET
ARLINGTON, VA 22217

DIRECTOR, ACOUSTIC TECHNOLOGY
 PROGRAM, CODE 222
OFFICE OF NAVAL RESEARCH
800 NORTH QUINCY STREET
ARLINGTON, VA 22217

DIRECTOR, PHYSIOLOGY PROGRAM
CODE 441
OFFICE OF NAVAL RESEARCH
800 NORTH QUINCY STREET
ARLINGTON, VA 22217

SPECIAL ASSISTANT FOR MARINE
 CORPS MATTERS, CODE 100M
OFFICE OF NAVAL RESEARCH
800 NORTH QUINCY STREET
ARLINGTON, VA 22217

COMMANDING OFFICER
ONR BRANCH OFFICE
ATTN: DR. J. LESTER
BUILDING 114, SECTION D
666 SUMMER STREET
BOSTON, MA 02210

COMMANDING OFFICER
ONR BRANCH OFFICE
ATTN: DR. CHARLES DAVIS
536 SOUTH CLARK STREET
CHICAGO, IL 60605

COMMANDING OFFICER
ONR BRANCH OFFICE
ATTN: DR. E. GLOYE
1030 EAST GREEN STREET
PASADENA, CA 91106

COMMANDING OFFICER
ONR BRANCH OFFICE
ATTN: MR. R. LAWSON
1030 EAST GREEN STREET
PASADENA, CA 91106

OFFICE OF NAVAL RESEARCH
SCIENTIFIC LIAISON GROUP
AMERICAN EMBASSY, ROOM A-407
APO SAN FRANCISCO 96503

DIRECTOR
NAVAL RESEARCH LABORATORY
TECHNICAL INFORMATION DIVISION
CODE 2627
WASHINGTON, D.C. 20375

DR. ROBERT G. SMITH
OFFICE OF THE CHIEF OF NAVAL
 OPERATIONS, OP987H
PERSONAL LOGISTICS PLANS
WASHINGTON, D. C. 20350

MR. ARNOLD RUBINSTEIN
NAVAL MATERIAL COMMAND
NAVMAT 0344
WASHINGTON, D.C. 20360

COMMANDER
NAVAL AIR SYSTEMS COMMAND
HUMAN FACTORS PROGRAMS, NAVAIR 340F
WASHINGTON, D.C. 20361

COMMANDER
NAVAL AIR SYSTEMS COMMAND
CREW STATION DESIGN, NAVAIR 5313
WASHINGTON, D.C. 20361

COMMANDER
NAVAL ELECTRONICS SYSTEMS COMMAND
HUMAN FACTORS ENGINEERING BRANCH
CODE 4701
WASHINGTON, D.C. 20360

CDR R. GIBSON
BUREAU OF MEDICINE & SURGERY
AEROSPACE PSYCHOLOGY BRANCH
CODE 513
WASHINGTON, D.C. 20372

LCDR ROBERT BIERSNER
NAVAL MEDICAL R&D COMMAND
CODE 44
NAVAL MEDICAL CENTER
BETHESDA, MD 20014

LCDR T. BERGHAGE
NAVAL MEDICAL RESEARCH INSTITUTE
BEHAVIORAL SCIENCES DEPARTMENT
BETHESDA, MD 20014

A. E. BISSON
CODE 1939
NSRDC
CARDEROCK, MD 20084

DR. JAMES CURTIN
NAVAL SEA SYSTEMS COMMAND
PERSONNEL & TRAINING ANALYSES
NAVSEA 074C1
WASHINGTON, D.C. 20362

DR. ARTHUR BACHRACH
BEHAVIORAL SCIENCES DEPARTMENT
NAVAL MEDICAL RESEARCH INSTITUTE
BETHESDA, MD 20014

DR. GEORGE MOELLER
HUMAN FACTORS ENGINEERING BRANCH
SUBMARINE MEDICAL RESEARCH LAB.
NAVAL SUBMARINE BASE
GROTON, CT 06340

MR. PHILLIP ANDREWS
NAVAL SEA SYSTEMS COMMAND
NAVSEA 0341
WASHINGTON, D. C. 20362

NAVY PERSONNEL RESEARCH AND
DEVELOPMENT CENTER
MANAGEMENT SUPPORT DEPARTMENT
CODE 210
SAN DIEGO, CA 92152

CHIEF
AEROSPACE PSYCHOLOGY DIVISION
NAVAL AEROSPACE MEDICAL INSTITU
PENSACOLA, FL 32512

DR. FRED MUCKLER
NAVY PERSONNEL RESEARCH AND
DEVELOPMENT CENTER
MANNED SYSTEMS DESIGN, CODE 311
SAN DIEGO, CA 92152

NAVY PERSONNEL RESEARCH AND
DEVELOPMENT CENTER
CODE 305
SAN DIEGO, CA 92152

DR. LLOYD HITCHCOCK
HUMAN FACTORS ENGINEERING DIVISION
NAVAL AIR DEVELOPMENT CENTER
WARMINSTER, PA 18974

ROBERT W. BRYANT
ASW-132
NAVSEA
NATIONAL CENTER #1
WASHINGTON, D.C. 20360

CDR P. M. CURRAN
HUMAN FACTORS ENGINEERING DIVISION
CREW SYSTEMS DEPARTMENT
NAVAL AIR DEVELOPMENT CENTER
WARMINSTER, PA 18974

LCDR WILLIAM MORONEY
HUMAN FACTORS ENGINEERING BRANCH
CODE 1226
PACIFIC MISSILE TEST CENTER
POINT MUGU, CA 93042

DR. J. D. HARRIS
NSMRL
SUBMARINE BASE
GROTON, CT 06340

HUMAN FACTORS SECTION
SYSTEMS ENGINEERING
TEST DIRECTORATE
U.S. NAVAL AIR TEST CENTER
PATUXENT RIVER, MD 20670

HUMAN FACTORS ENGINEERING BRANCH
NAVAL SHIP RESEARCH AND
DEVELOPMENT CENTER
ANNAPOLIS DIVISION
ANNAPOLIS, MD 21402

DR. ROBERT FRENCH
NAVAL OCEAN SYSTEMS CENTER
SAN DIEGO, CA 92152

DR. JERRY C. LAMB
DISPLAY BRANCH
CODE TD112
NAVAL UNDERWATER SYSTEMS CENTER
NEW LONDON, CT 06320

NAVAL TRAINING EQUIPMENT CENTER
ATTN: TECHNICAL LIBRARY
ORLANDO, FL 32813

HUMAN FACTORS DEPARTMENT
CODE N215
NAVAL TRAINING EQUIPMENT CENTER
ORLANDO, FL 32813

DR. ALFRED F. SMODE
TRAINING ANALYSIS AND EVALUATION
NAVAL TRAINING EQUIPMENT CENTER
CODE N-OOT
ORLANDO, FL 32813

DR. GARY POOCK
OPERATIONS RESEARCH DEPARTMENT
NAVAL POSTGRADUATE SCHOOL
MONTEREY, CA 93940

MR. WARREN LEWIS
HUMAN ENGINEERING BRANCH
CODE 8231
NAVAL OCEAN SYSTEMS CENTER
SAN DIEGO, CA 92152

DR. A. L. SLAFKOSKY
SCIENTIFIC ADVISOR
COMMANDANT OF THE MARINE CORPS
CODE RD-1
WASHINGTON, D.C. 20380

MR. J. BARBER
HQS, DEPARTMENT OF THE ARMY
DAPE-PBR
WASHINGTON, D.C. 20546

DR. JOSEPH ZEIDNER
TECHNICAL DIRECTOR
U.S. ARMY RESEARCH INST.
5001 EISENHOWER AVENUE
ALEXANDRIA, VA 22333

DIRECTOR, ORGANIZATIONS AND
SYSTEMS RESEARCH LABORATORY
U. S. ARMY RESEARCH INSTITUTE
5001 EISENHOWER AVENUE
ALEXANDRIA, VA 22333

TECHNICAL DIRECTOR
U.S. ARMY HUMAN ENGINEERING LA
ABERDEEN PROVING GROUND
ABERDEEN, MD 21005

U.S. ARMY AEROMEDICAL RESEA[illegible] LAB
ATTN: CPT GERALD P. KRUEGER
FT. RUCKER, AL 36362

U.S. AIR FORCE OFFICE OF
SCIENTIFIC RESEARCH
LIFE SCIENCES DIRECTORATE, NL
BOLLING AIR FORCE BASE
WASHINGTON, D.C. 20332

DR. DONALD A. TOPMILLER
CHIEF, SYSTEMS ENGINEERING BRANCH
HUMAN ENGINEERING DIVISION
USAF AMRL/HES
WRIGHT-PATTERSON AFB, OH 45433

AIR UNIVERSITY LIBRARY
MAXWELL AIR FORCE BASE, AL 36112

DR. ROBERT WILLIGES
HUMAN FACTORS LABORATORY
VIRGINIA POLYTECHNIC INSTITUTE
130 WHITTEMORE HALL
BLACKSBURG, VA 24061

DR. HARRY SNYDER
DEPT OF INDUSTRIAL ENGINEERING
VIRGINIA POLYTECHNIC INSTITTUTE
AND STATE UNIVERSITY
BLACKSBURG, VA 24061

DR. ARTHUR I. SIEGEL
APPLID PSYCHOLOGICAL SERVICES
404 EAST LANCASTER STREET
WAYNE, PA 19087

DR. ROBERT R. MACKIE
HUMAN FACTORS RESEARCH, INC.
5775 DAWSON AVE
GOLETA, CA 93017

DR. GERSHON WELTMAN
PERCEPTRONICS, INC.
6271 VARIEL AVENUE
WOODLAND HILLS, CA 91364

DR. J. A. SWETS
BOLT, BERANEK & NEWMAN, INC
50 MOULTON STREET
CAMBRIDGE, MA 02138

DR. ALPHONSE CHAPANIS
DEPT OF PSYCHOLOGY
THE JOHNS HOPKINS UNIV
BALTIMORE, MD 21218

DR. MEREDITH CRAWFORD
GEORGE WASHINGTON UNIV.
SUITE 805
2101 L ST., N. W.
WASHINGTON, D.C. 20037

DR. WILLIAM HOWELL
DEPARTMENT OF PSYCHOLOGY
RICE UNIVERSITY
HOUSTON, TX 77001

JOURNAL SUPPLEMENT ABSTRACT SERVICE
AMERICAN PSYCHOLOGICAL ASSOCIATION
1200 17TH STREET, N. W.
WASHINGTON, D.C. 20036

DR. ROBERT G. PACHELLA
UNIVERSITY OF MICHIGAN
DEPT. OF PSYCHOLOGY
HUMAN PERFORMANCE CENTER
330 PACKARD ROAD
ANN ARBOR, MI 48104

DR. T. B. SHERIDAN
DEPT OF MECHANICAL ENGINEERING
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
CAMBRIDGE, MA 02139

DR. JESSE ORLANSKY
INSTITUTE FOR DEFENSE ANALYSES
400 ARMY-NAVY DRIVE
ARLINGTON, VA 22202

DR. STEPHEN J. ANDRIOLE
ADVANCED RESEARCH PROJECTS AGENCY
1400 WILSON BLVD
ARLINGTON, VA 22209

DR. STANLEY DEUTSCH
OFFICE OF LIFE SCIENCES
HQS, NASA
600 INDEPENDENCE AVE.
WASHINGTON, D.C. 20546

DR. J. MILLER
NASA
11400 ROCKVILLE PIKE
ROCKVILLE, MD 20852

DR. WILLIAM A. MC CLELLAND
HUMAN RESOURCES RESEARCH OFFICE
300 N. WASHINGTON STREET
ALEXANDRIA, VA 22314

DR. WILLIAM R. UTTAL
DEPT OF PSYCHOLOGY, GARTLEY HALL
UNIV OF HAWAII AT MANOA
HONOLULU, HI 96822

DR. W. S. VAUGHAN
OCEANAUTICS, INC
422 6TH ST
ANNAPOLIS MD 21403

DR. DAVID GETTY
BOLT, BERANEK & NEWMAN
50 MOULTON STREET
CAMBRIDGE, MA 02138

DIRECTOR, HUMAN FACTORS WING
DEFENSE & CIVIL INSTITUTE OF
ENVIRONMENTAL MEDICINE
P.O. BOX 2000
DOWNSVILLE, TORONTO, ONTARIO
CANADA

DR. A.D. BADDELEY
DIRECTOR, APPLIED PSYCH. UNIT
MEDICAL RESEARCH COUNCIL
15 CHAUCER ROAD
CAMBRIDGE, CB2 2EF
ENGLAND